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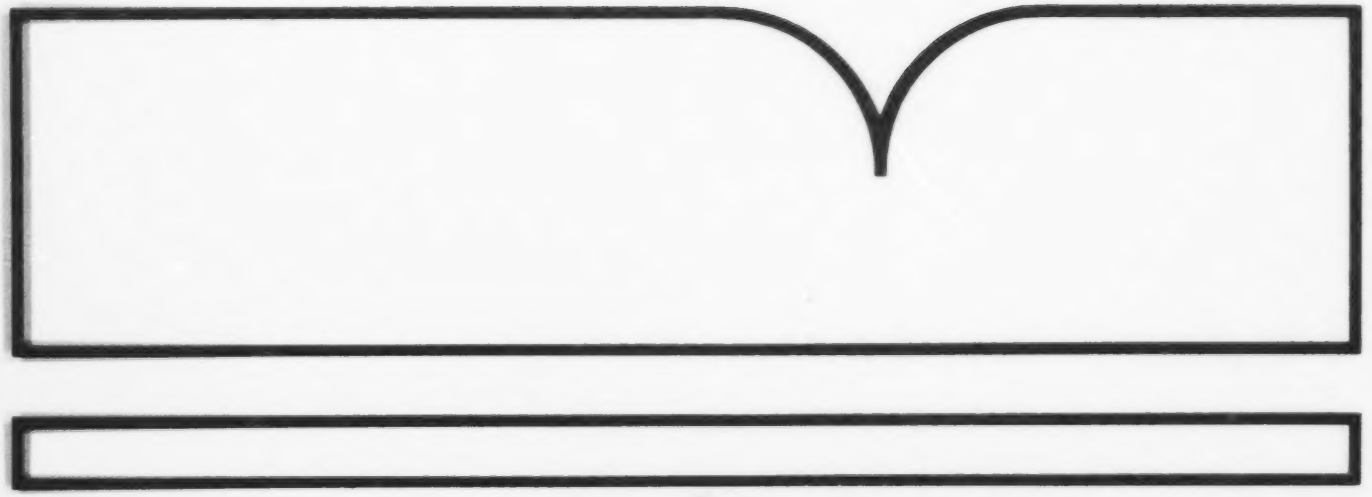

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A REVIEW OF THE CANADIAN AND SWEDISH EXPERIENCE FOR THE CONTROL OF INDOOR RADON

by

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16. ABSTRACT The paper reviews Canadian and Swedish experience in controlling indoor radon. Interest in and concern about elevated levels of radon (Rn) and radon daughters (RnD) in the indoor environment have been growing steadily during the last 10 years. During this period the federal governments of Canada and Sweden, in conjunction with provincial authorities, have developed a coordinated response or program for reducing the national health risk of indoor Rn/RnD exposure. The focus of these programs is on (1) characterizing and/or locating the problem areas or dwellings, and (2) providing demonstrated control approaches to deal with the indoor Rn/RnD problem. The investigations by Canada and Sweden have identified numerous control approaches that are effective when they are applied appropriately and carefully. Among these control techniques are the use of subfloor (depressurization) ventilation, crawlspace ventilation, house ventilation, and new construction practices such as monolithic pours with floor/wall joint sealing.

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A REVIEW OF THE CANADIAN AND SWEDISH EXPERIENCE FOR THE CONTROL OF INDOOR RADON

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Interest in and concern about elevated levels of radon and radon daughters in the indoor environment have been steadily growing during the last 10 years. During this period the Federal governments of Canada and Sweden in conjunction with provincial authorities have developed a coordinated response or program for reducing the national health risk of indoor radon/radon daughter exposures. The focus of these programs is on (1) characterizing and/or locating the problem areas or dwellings and (2) providing demonstrated control approaches to deal with the indoor radon/radon daughter problem. The investigations by Canada and Sweden have identified numerous control approaches that are effective when they are appropriately and carefully applied. Among these control techniques are the use of subfloor (depressurization) ventilation, crawlspace ventilation, house ventilation, and new constructon practices such as monolithic pours with floor/wall joint sealing.

Introduction

The interest in and concern for Rn and its decay products, RnD, in the indoor environment have increased greatly in the last 10 years. This growing interest and concern resulted in numerous government and private sector investigative activities.

The basis for this interest and concern is derived from an indication in the early 1970's that (1) excessive lung cancer frequencies among uranium and nonuranium miners were associated with exposures to RnD, (2) evidence that mining wastes and high U or Ra content building materials may be causing unacceptable exposures to RnD, and (3) selected measurement projects were suggesting the potential for a more extensive exposure to Rn and RnD in natural environmental settings.

In 1977 the International Commission on Radiological Protection (ICRP) issued its landmark Publication No. 26 in which for the first time it was recommended that natural radiation should be addressed in accordance with the same principles applicable to radiation arising from human activity.

Around this time frame, 1977, the governments of Canada and Sweden, with specific problems in mind, started to take formal action.

Overview of the Canadian and Swedish Programs

In 1976, the Canadian Federal Provincial Task Force on Radioactivity was established, and in 1979 the Swedish Radon Commission was established. These groups, through their mandates from their respective Federal governments, took leadership roles in directing or guiding investigations which would provide information regarding:

1. The extent of Rn/RnD concentrations in residential and commercial dwellings on regional and national bases.

2. The source of elevated indoor Rn/RnD concentrations.

3. Identification of the nature of the relationship of environmental factors to the indoor Rn/RnD problem concentrations.

4. Cost effective solutions to mitigate or prevent elevated Rn/RnD concentrations in existing and new houses.

Tables 1 and 2 present the chronologies for Canadian and Swedish activities in these task areas, the Federal executive agencies involved, and the salient guidance or criteria developed in the respective programs.

The chronologies of events are, in effect, case studies which reflect not only government responses to assessments of technical information gathered over a period of time, but also reflect consistency with established institutional and policy limitations.

Although it is not the purpose of this paper to critique the Canadian and Swedish programs, the value of the chronology to other developing national programs would be lost if it did not inspire questions or comparisons such as:

1. In a national program to reduce the cancer risk from RnD, what is the most cost effective allocation of research (investigative) funding between (a) identifying the extent of exposures and (b) developing cost effective radon preventive ative or mitigative techniques for use in dwellings?

2. If, as in Canada, RnD monitoring program survey information on housing type, occupant behavior, or infiltration has not been highly correlated to indoor concentrations of Rn/RnD, then should not other more focused quantitative data be collected?

Monitoring Rn/RnD Concentrations in Canada and Sweden

There is little debate that some level of random sampling to establish an estimate of the extent of any national problem is necessary. In this regard there was little difference in the direction that both the early Canadian and Swedish monitoring programs took, viz., to focus monitoring attention on suspected problem areas and environments. Canada looked to the uranium mining areas and Sweden looked to houses where lightweight alum-shale concrete had been used.

Tables 3 and 4 summarize statistics for observed Rn/RnD concentrations on provincial or regional and national bases. Of special interest to the Canadian and Swedish governments was to establish the percentage of the national population of houses which could exceed proposed or adopted Rn or RnD concentration action levels. In Canada this meant looking at the 0.02 WL RnD concentration and in Sweden looking at the 70, 200, and 400 Bq m^{-3} RnD concentrations depending on whether the housing was new construction, rebuilt, or existing.

The salient distinctions between the Canadian and Swedish radon control development experiences, given that both programs started about the same time, seem to be:

1. The Canadian effort from 1977-1980 was characterized by an intensive effort to quickly demonstrate a limited number of radon control techniques while remediating a highly visible radiation problem in uranium mining areas.

2. The Swedish experience reflects a longer term effort, looking at a wider range of radon control techniques with special emphasis on evaluation of the cost effectiveness or cost-benefit aspects of applied controls.

It must be acknowledged that the above approaches were obviously developed in conscious response to governmental policies and, very importantly, the availability of monies to carry out the intended research and development.

Results of the Radon Control Programs

It is now generally recognized that the major source of Rn entry into

dwellings is via the infiltration of soil gas. This was not understood at the inception of the Canadian and Swedish radon control programs. In fact prior to 1976 remediation in Port Hope, Ontario, and Uranium City, Saskatchewan, forced air ventilation was the only remedial technique applied. The initial Swedish efforts also looked to the demonstration of whole house ventilation to control what was initially thought to be an indoor RnD problem arising from radon emanation from building materials.

Tables 5 and 6 summarize the results of the Canadian and Swedish experience with the use of (1) subfloor depressurization ventilation systems, (2) whole house ventilation, (3) crawlspace ventilation, (4) sealing of utility penetrations of the house shell, and (5) sealing of new house foundations.

Tables 7 and 8 provide implementation specifications where available and approporiate for the five radon control techniques listed above.

Conclusions

1. The Canadian and Swedish radon control programs are mature; i.e., they have defined (a) goals and objectives, (b) governmental (federal and provincial) responsibilities and roles in meeting those goals, (c) criteria to evaluate how well goals are being met, and (d) continuing programs to enhance compliance with program objectives (e.g., monitoring and/or control technique development).

2. The Swedish Federal program is predicated on an active and important role for provincial and local governments in locating, addressing, or ensuring compliance with public health goals; e.g., compliance with the Radon Commission action levels.

3. The Canadian and Swedish programs, to variable degrees, have ensured that federal action level guidance will be complied with by incorporating such guidance as performance criteria in national and/or provincial building codes.

4. The Canadian and Swedish programs have demonstrated the ability of the following radon control techniques to perform in a consistent and predictable manner when properly and appropriately installed:

    a. Subfloor depressurization systems.
    b. Crawlspace ventilation systems with sealing.
    c. House ventilation systems.
    d. Sealing around utility substructure penetrations.
    e. Sealing using monolithic poured concrete.

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TABLE 1 - CHRONOLOGY OF CANADIAN PROGRAM [1,2,3,4]

Date	Lead Organization	Responsibilities	Results
February 1976	Federal Provincial Task Force on Radioactivity, AECB	Coordinate National Program of Radioactive Contamination Assessment and Remedial Measures	
1976	Rio Algom Ltd. R&D Survey of Company Housing	Indentify houses for remediation	
April 1977	Atomic Energy Control Board (AECB)	Establish "Criteria for cleanup in Canada"	Criteria incorporated in Ontario Building Code by Provincial Assessment Board
1977	AECB, Canada Survey of Housing on Elliott Lake	• Identify problem houses RnD>0.02WL 671 surveyed 117 with problem	National Building Code amended to require new house in Elliott Lake to be below 0.02 WL before occupancy
	AECB, Rio Algom Ltd., Canada Mortgage and Housing Corporation (CMHC) NRC Division of Building Research	• Investigate Ra in soil • Investigate Rn transport in soil • Investigate and test techniques to locate entry	
1977	Canada Mortgage and Housing Corporation (CMHC)	Required guaranteed (Rn) countermeasures in new building design for Elliott Lake	
1977, 1978 1980	Department of National Health and Welfare (Cross Canada Survey)	19 City Survey • National assessment Ra/RaD concentratons in residences	Further studies where high Ra/RnD concentrations were observed
		• Correlate problem houses with meteorology, geology, house construction, occupancy characteristics	Multiple regression analyses showed no "high correlation with survey factors other than window open parameter

TABLE 2 - CHRONOLOGY OF SWEDISH PROGRAM [5,6,7]

Date	Lead Organization	Responsibilities and Results
May 1978	National Institute of Radiation Protection	Measured high Rn concentrations built on alum shale tailings
Begin 1979	Radon Commission	Established to address the need for protective measures against radiation hazards in buildings
May 1979	Radon Commission	Issued provisional remediation action levels 400/200/70 Bq M^{-3} for existing remodeled and new houses
		Initiated studies to establish basis for recommendations
1979	Local Authorities	Initiated surveys to find problem (> 400 Bq m^{-3}) houses
1980	Radon Commission	Swedish Building Code provide limits on RnD concentrations and gamma radiation in planned houses
		Provide limits on RnD concentrations in rebuilt houses
	National Board of Health and Welfare	Established an action level for RnD concentrations in existing houses

(continued)

TABLE 2 - CHRONOLOGY OF SWEDISH PROGRAM [5,6,7] (CONT'D)

Date	Lead Organization	Responsibilities and Results
1982	National Board of Physical Planning and Building	Proposed a System for Classification of Ground for Radon Risk to Houses
		Recommended technical measures to reduce indoor Rn concentrations
	National Authority for Testing	Maintain measurement calibration facility and records for measurement consultants
January 1983	Radon Commission	Recommended retaining restrictions on building materials and keeping RnD concentrations as low as reasonably achievable
		Radon safe construction Radon protective construction Conventional construction identified
December 1985	National Institute of Radiation Protection	Mandated responsibility for radiation monitoring developments in dwellings
		Responsible for assessment of risks and measurement techniques
	Board of Health and Welfare	Mandated, along with National Board of Physical Planning and Building, to establish limits for RnD

TABLE 3 - CANADIAN MONITORING RESULTS [2,3]

Location	Period	Number of Houses	Rn Concentrations* Bq m^{-3}	RnD Concentrations* WL	Percent Houses > 148 Bq m^{-3} or > 0.02WL
Cross Canada	June-August '77 June-August '78 June-August '80	13,457 (19 cities)	5.2-57.0	0.0009-0.0058	9+
Port Hope	--	2,960		0.0029	
Elliott Lake	Fall '76	1,921		0.008	
Uranium City	Feb-June '76	632		0.013	
Bancroft	Summer '77	1,162		0.007	
Saskatchewan	Summer-Fall '80	2,573		0.0031-0.0175	

* Geometric Mean based on grab sampling data

+ Based on survey of 9999 houses through August 1978

TABLE 4 - SWEDISH MONITORING RESULTS [6,8,9]

Location	Period	Number of Houses	Rn Concentrations (Bq/m^{-3})	RnD Concentrations (Bq/m^3)	Percent Houses with Noted Concentrations
Nationwide	--	6,326	0-199		52
		4,050	200-399		34
		1,545	400-1000		13
		162	> 1000		1
38% in Stockholm Co.	Through June '82	25,500		mean = 122 median = 65	
			> 800	> 400	2
Nationwide	--	47,072*	--	maximum = 1140	
				> 148	81

* Some of the above sampling was targeted at high areas

TABLE 5 - CANADIAN MITIGATION SYSTEM RESULTS [4,10,11]

Location	System	Number of Houses	Number >0.02 WL or 148 Bq m^{-3}	Cost ($ Canada)	System Experience
Elliott Lake	Subfloor Vent 77/78	234 (260)	2		Within 18 mo: 15 fan replacements, 7 homeowner tampering, 12 fans replaced as too noisy, backblow, leakage, and 4 sealing failures
	Subfloor Sealing* 77/79	140	0		
	Crawl Space Vent* 76/77	23	0		
Bancroft	Subfloor Vent	53	3	1500-11500	
Port Hope	Subfloor Vent	31	1	4800-26300	

* New construction

TABLE 6 - SWEDISH MITIGATION SYSTEM RESULTS [12,13,14,15]

System	Number of Houses	Bq m^{-3} Number > 400 RnD	Cost (SEK)*	Percent Reductions
Subfloor Vent	9	3	20,000-70,000	45-90
Subfloor Vent (new construction)	39+	0	5,000-10,000	83-90
Sealing Utility	18	-	100 SEK + 2 hours	80
Ventilation, House	7	0	20,000-27,000	71-96
Crawlspace Ventilation (new construction)	100	0	0-15,000	-
Monolithic Slab with Radon Barrier (new construction)	48	0	-	-

* 8 SEK = $1.00 U.S. (1984)

+ 100 House Program

TABLE 7 - CANADIAN SYSTEM SPECIFICATIONS [1,4,11]

System Type	Collection*	Air Mover*	Exhaust*	Problems
Subfloor Ventilation	Perimeter "weepingtile" inside and outside footing connected to sump	50 cfm fan	Flexible hose 3" through band joist	28 mo - fan failures - tampering
	Below slab network of tile	6"-10" fans 80-150 cfm @ 0.3" WC	Center stack to roof	18 mo - fan failures - tampering - sealing failures - too noisy
	Below slab network of tile	Passive (failed in warm weather)	Center stack to roof	
Crawlspace Ventilation (new construction)	6 mil polyethylene barrier above tight plywood subflooring	Design 1 ach+ in crawlspace	--	--
Sealed Basement System (new construction)	reinforcing mesh in 4" 3000 psi concrete slab; floorwall joint form void with polysulfide sealing; under-slab soil compacted	--	--	None

* Metric equivalents: 1 cfm = 0.00047 m^3/sec; 1 in. = 0.0254 m; 1 in. WC = 248 Pa;
1 mil = 0.0000254 m; 1 psi = 0.0703 kg/cm^2

\+ Ach = air changes per hour

-- Not applicable or not reported

TABLE 8 - SWEDISH SYSTEM SPECIFICATIONS [12,13,14,15]

System Type	Collection	Air Mover	Exhaust	Problems
Subfloor Ventilation	1-5 "suck holes"	0.04 m^3s^{-1} @ 300 Pa 100 W fan	50 mm PVC	None to date
	6-8 (10^{-3}) m^3s^{-1} per hole			
	0.3 m diameter "suck hole"			
Subfloor Ventilation (new construction)	Same as above	Same as above	Same as above	--
Sealing Utility Entrance	Sealed out 19,000 Bq/m^{-3} soil gas estimated to infiltrate 2% of house air	--	--	--
Crawlspace Ventilation	Asphalt painted slab in same crawlspace. (Crawlspace air was 4600 Bq m^{-3}.)	Natural ventilation	Crawlspace vents or natural draft roof stack	--
Ventilation, House	Increased air changes from 0.35-0165 ach*	--	--	--
Monolithic Slab	Monolithic concrete slab barrier on grade in some cases with ducts	Passive ventilation under slab		

* Ach = air changes per hour

-- Not applicable or not reported